# TIDES AND TIDAL DRAINAGE
## IN THE
# NORTHEASTERN STATES

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# TIDES AND TIDAL DRAINAGE IN THE NORTHEASTERN STATES

## General

Areas of agricultural land located along coastal rivers, estuaries, bays, and the open seas of the Northeastern states are subjected in varying degree to overflow and impaired drainage by tidal waters. These areas range from a few acres to several hundred acres. The extent and frequency of overflow and drainage impairment may vary widely, depending on the elevation and exposure of the sites to open tidal water.

Protection from overflow usually is obtained by the enclosure of such areas with dikes. Drainage may be obtained by establishing a system of internal drains, with water discharged through the dikes by pumps, gravity flow through gated structures, or by a combination of pumps and gated structures.

Pumps are necessary when: (1) Insufficient storage for accumulating drainage waters within ponding areas, ditches, and the soil profile is available during periods of gate closure; (2) when flow through the gates is restricted over long periods by excessive wind tides, flood flows, or inadequate outlets into open tidal waters; or (3) when construction and maintenance of foreshore channels are impractical.

The gravity outlet ditch with a gated structure provides suitable means for removing drainage waters from most tidal sites. The gated structure consists of a box or pipe culvert through the dike with the gate placed at the tidewater end of the structure. The gates may be circular, square, or rectangular in shape. Usually these are made of cast iron and provided with single or double acting hinges at the top. Well-made gates, when properly installed, are so finely balanced that they automatically open to outflow or close against backflow at slight differences in head. Large drainage areas may require several gated structures or a battery of culverts and gates incorporated in one structure.

Design of the open ditch and gated structure for discharging water against constantly fluctuating tides involves unsteady flow conditions which cannot be solved by steady flow procedures ordinarily encountered in channel work. Neither are the solutions contained in handbooks and texts which are commonly available.

## Scope

The following covers briefly the tidal phenomenon and essential procedures that can be used in the design and construction of gated gravity channels for draining tidal <u>agricultural</u> land.

Information on dike design and construction, treatment of organic soils usually associated with tidal sites, and establishment of field drainage systems are not included since reference can be made to Section 16 of the National Engineering Handbook and drainage sections of state handbooks on these subjects. References to soils, crop adaptation, and management of tidal lands should be available in local technical and drainage guides.

Discussion, charts, and examples are limited also to the circular metal pipe culvert and timbered outlet structure. Their generally low cost and ease of installation, as compared with other materials, have shown them to be the most practical type of installation for Northeastern agricultural tide land sites. However, concrete or other suitable materials may be used in constructing the outlet structure.

## Action of Tides

The action of tides is a complex phenomenon, some general knowledge of which is essential to the planning and construction of any works affected by them. Only a few essential facts will be discussed herein. More detailed information is available in manuals of the United States Coast and Geodetic Survey, its annual tide tables of the East Coast of North and South America, and several texts. "Tidal Hydraulics," by George Pillsbury, published by the Corps of Engineers, is a useful reference.

## Some Tidal Terms and Definitions

The tide is the regular periodic rise and fall of the surface of the oceans. Concurrent horizontal movements of surface waters as the result of tide-producing forces, occurring either as drifts in the open ocean or as flow through entrances into tidal basins and up tidal streams are known as tidal currents.

The component of the tide produced by harmonic action of tide-producing forces is referred to as the equilibrium tide. The irregular fluctuations of the tide caused by winds and variations in barometric pressure over water surfaces are referred to as the meteorologic tides.

The path of a point at a particular station which traces the water surface elevation against time through a lunar or tidal period is the tidal curve for that station. The maximum elevation or crest reached by the rising limb of the tidal cycle (flood tide) is called the high water. The maximum depression or trough reached by the falling limb (ebb tide) is called the low water. The average height of all low waters at a station over a period of time is the mean low water. Similarly, the average height of all high water at a station over a period of time is the mean high water. The difference in height between high water and low water is the tidal range. The mean tidal range is the

average of differences between all high waters and all low waters. The extreme range is the maximum that has been observed.

Because of variation in density of ocean water with changes in temperature, salinity and barometric pressure, and because of differences in wind and rain from place to place, mean sea level at different tidal stations may not be on the same geodetic level surface. Mean sea level, thus, is an actual mean of sea levels determined from a long series of tidal observations taken over a number of selected points. The plane of zero reference in the United States is established by the Coast and Geodetic Survey from which local points of reference, called datum, are established. On the Atlantic coast, such datum is mean low water. Established datum for several Atlantic coastal points are: -4.9 at Boston,-3.1 at Philadelphia,-0.6 at Baltimore, and-1.3 at Hampton Roads.

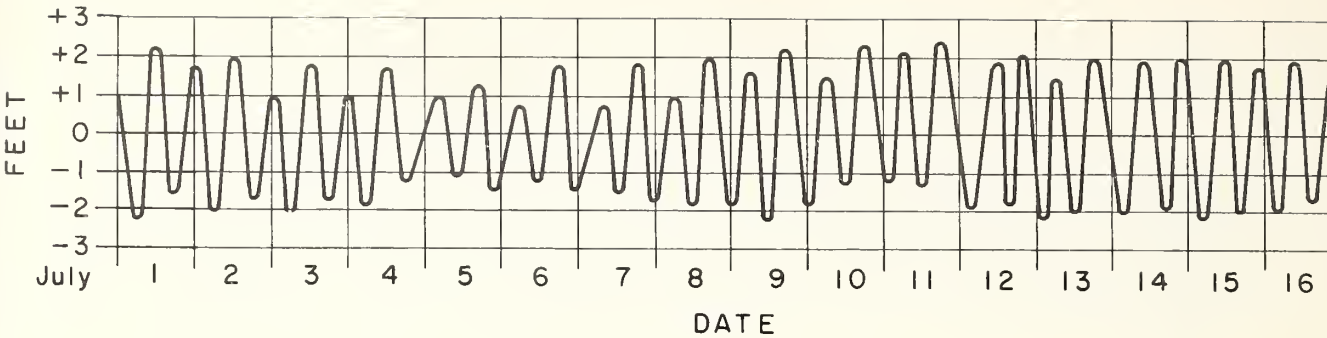
Tides may be diurnal, semi-diurnal, or mixed. Tides with but one high and low each lunar day are diurnal. Diurnal tides occur over the greater part of each month along coastal areas of the Gulf of Mexico. Semi-diurnal tides have two nearly equal high waters and two nearly equal low waters each lunar day. Such tides are common to most coastal waters of the world and are the type occurring along the coast of the Northeastern States. Since the differences between the two high waters and between the two low waters on the northeast coast are relatively small (mostly well under one foot), no distinction is made between daily high waters or between daily low waters. Mixed tides are those which have two quite unequal high waters, two unequal low waters, or both during the course of a lunar day. Mixed tides occur on both the west coast of the United States and Europe.

The highs of high waters and lows of low waters also vary from day to day during the course of a lunar month and during the course of a solar year. The highest high waters and lowest low waters during the course of a lunar cycle occur shortly after full and new moons and are known as Springs. Lowest high water and highest low waters occur shortly after the first quarters and third quarters of the moon and are known as Neaps. Springs and Neaps change progressively from month to month, usually being highest near the Spring and Autumn equinoxes and lowest near the Summer and Winter solstices.

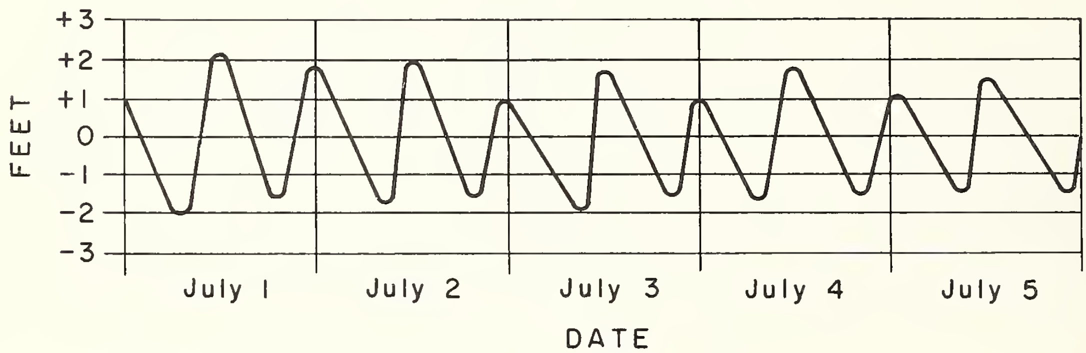
In the Northeastern States, the swings produced by such Springs and Neaps are not sufficiently large to warrant their special consideration in determining the normal tidal ranges necessary in design of drainage outlets. However, when extremes occur concurrently with storm tides, their effects are significant in considering extreme tides for dike heights.

## Tidal Phenomenon

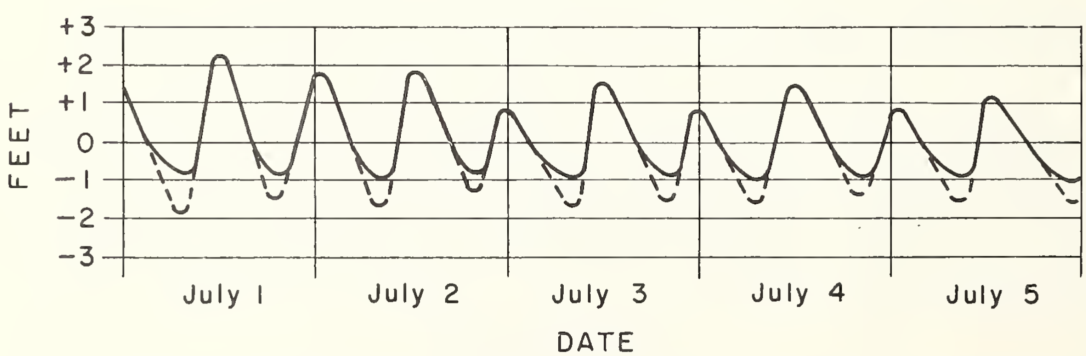
Tides are the result of a number of complex forces acting upon the earth's mass. The dominant component of these forces is the equilibrium tide, which develops from the gravitational attraction




OCEAN TIDES ON OPEN COASTLINE




RIVER ESTUARY TIDES




RIVER ESTUARY TIDES WITH SILTED FORESHORE

# CHARACTERISTIC TIDES

Figure 1

between earth, moon, and sun; and the constant harmonic changes in such pulls over the surfaces of the oceans and seas as the result of the rotation of the moon in its orbit about the earth and the spinning earth in its orbit about the sun. The range of the equilibrium tides differs from place to place. Along the Atlantic coastline of the United States, such variations range from a fraction of a foot in Gulf Coast waters up to 40 feet in the Bay of Fundy. (For more detailed information on forces producing equilibrium tides, see Appendix A.)

The changing effect of lunar and solar pulls during the course of their travel cancel out or augment each other progressively during the months and year. This results in the gradual tidal swings which may be as much as 2 to 10 feet in some part of the earth's waters. However, such swings remain comparatively small along tidal waters of the northeast coast. Figure 1 illustrates some typical tides.

Violent fluctuations of water levels at a tidal station may result from strong onshore or offshore winds caused by hurricanes or other storms, such as "Northeasters". Water heights may be raised many feet. However, since both high and low waters are raised, such meteorologic tides are considered to be a raising of the mean sea level.

## Tide Curves

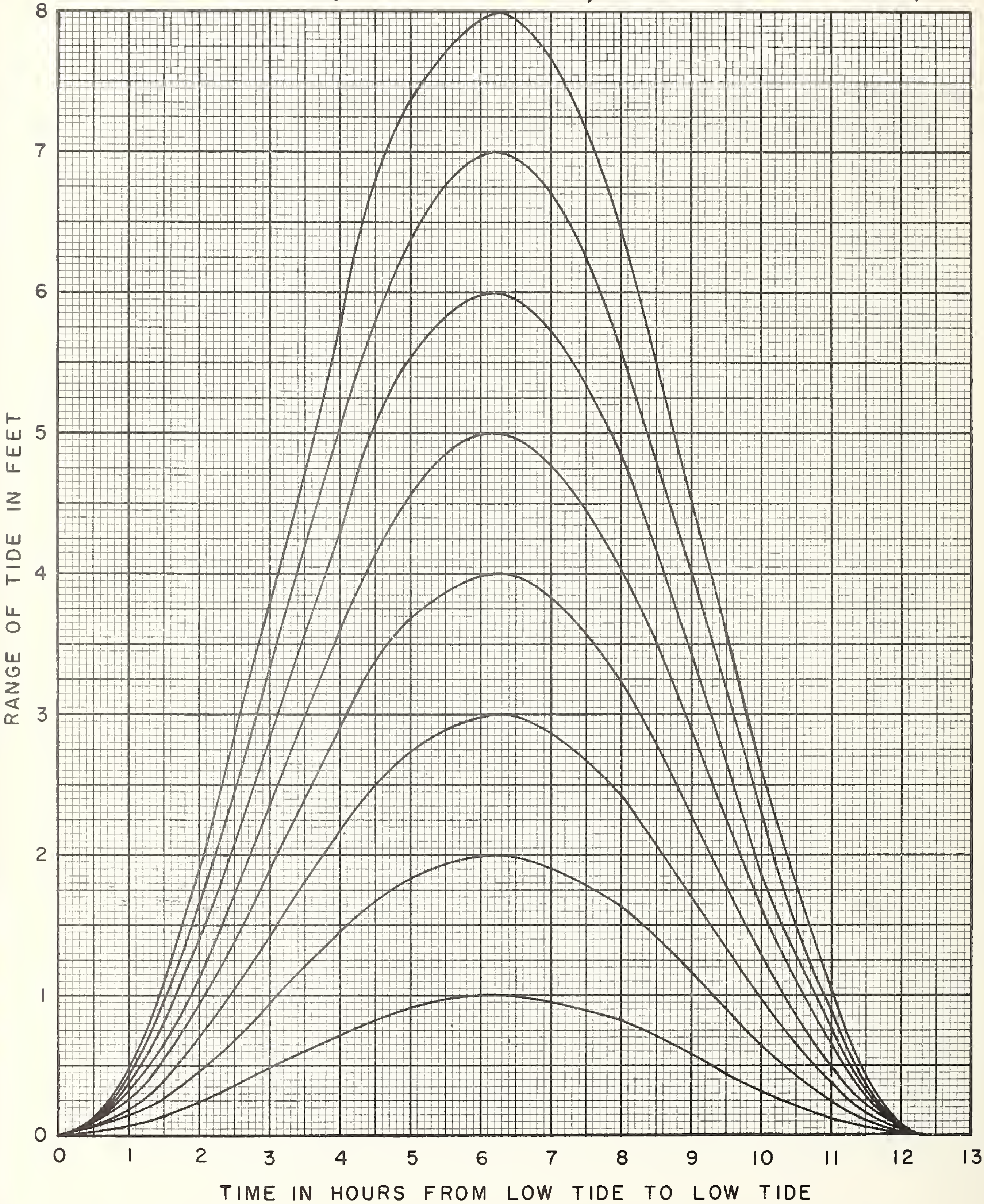
The theoretical oscillations of tides in the open ocean and coastal waters conform to the mathematical cosine curve. See figure 2 for theoretical curves for various ranges of tide. Bays and sounds affect such undulations primarily by delaying the times of high and low water occurrence. Size, shape and alignment of coastal indentations may also decrease the net tidal swings. River estuaries affect the tide in varying degree, depending upon the size of the river, its hydraulic gradient and stage of river discharge. Their most characteristic effect on the tidal curve is to prolong the ebb tide. At low stages, water may flow up rivers in conformance to the open water tide curves. As river flow increases, tide swings become less and less. At high flood stages, effects of tides may be obliterated only a few miles upstream. Silted foreshores affect the water level oscillations by limiting the low elevations to which water might fall. The effect is on the low tide, whereas high tides tend to pour over deposits and rise to about the same elevation as if no silt deposits were present.

## Determination of Local Tide Data from Observations and Records

Tide data is best determined by direct observation at the site. Staff and automatic gages are used for this purpose. The staff gage is essentially a graduated board, set vertically at the edge of tidal water so that height and time of occurrence can be read by an observer. Markings on the staff are usually graduated in feet and tenths for ease in reading at a distance.

The automatic gage may be either of the float or bulb type, recording the elevations at a reduced scale on clock driven charts.

(Open coastal or bay water unaffected by silted foreshore or rivers.)




# THEORETICAL TIDE CURVE

Figure 2

A staff gage should be installed along with automatic gages to provide a means of checking and calibrating the automatic gages when necessary. The bulb-type gage usually is less accurate than the float-type gage. However, the bulb gage is sufficiently accurate for obtaining drainage design data and is quite desirable because of the ease in which it can be installed and removed for short period setups at poorly accessible sites. Gages should be referenced to accurate bench marks that are well protected against damage or destruction. For convenience, gages should be set with their zeros at established local datum. Observed staff gage readings should be taken over several tidal cycles. Where automatic gages can be used, readings should be carried over a lunar month if possible. Readings should be taken when little or no winds occur or over long enough periods when effects of wind can be evaluated. Where their effects are substantial, readings should be taken between spring and neap tides.

Onsite data should be correlated with the nearest available local gages and records. These not only provide a means of evaluating minor local effects, but make it possible to project to the site the major fluctuations caused by wind tides or river floods from the long-time records of other gages.

Adequacy of local records may vary but good sources usually are available from nearby operating stations of the Corps of Engineers, Coast Guard, and Coast and Geodetic Survey. Municipalities and port authorities often have complete and accurate records. Information on extreme high waters can sometimes be traced to local events recorded in old newspapers or community records and by inquiries of local inhabitants. If elevation of either or both low and high waters and tidal ranges are known, and effects of local distortions to the flood or ebb tide are insignificant, a reasonably accurate site curve can be established by use of theoretical curves in figure 2.

The first two columns in table 1 illustrate the record for an observed tidal cycle obtained by an observer from watch and staff-gage readings taken at hourly intervals. This data plotted in figure 3 shows the resulting tidal curve. The time period between the falling and rising limbs of the curve gives the time of play or period of operation of the gate when the elevation of forebay waters is higher than the elevation of tidal waters.

## Site Investigations and Surveys

Surveys and investigations should include all of the land to be protected and drained, as well as all foreshore areas leading to the tide water outlet. These should be made in the manner prescribed in Section 16 of the National Engineering Handbook and in State Engineering Handbooks. Sufficient topography and soil borings are necessary to establish the best locations for dikes, gated structures, and outlet ditches on the basis of accessibility, supporting foundations, protection from wash, and adequacy of outlet. Sites should be selected with soils sufficiently firm to support the structure without resorting to

Table 1

Tide Gate Design Data

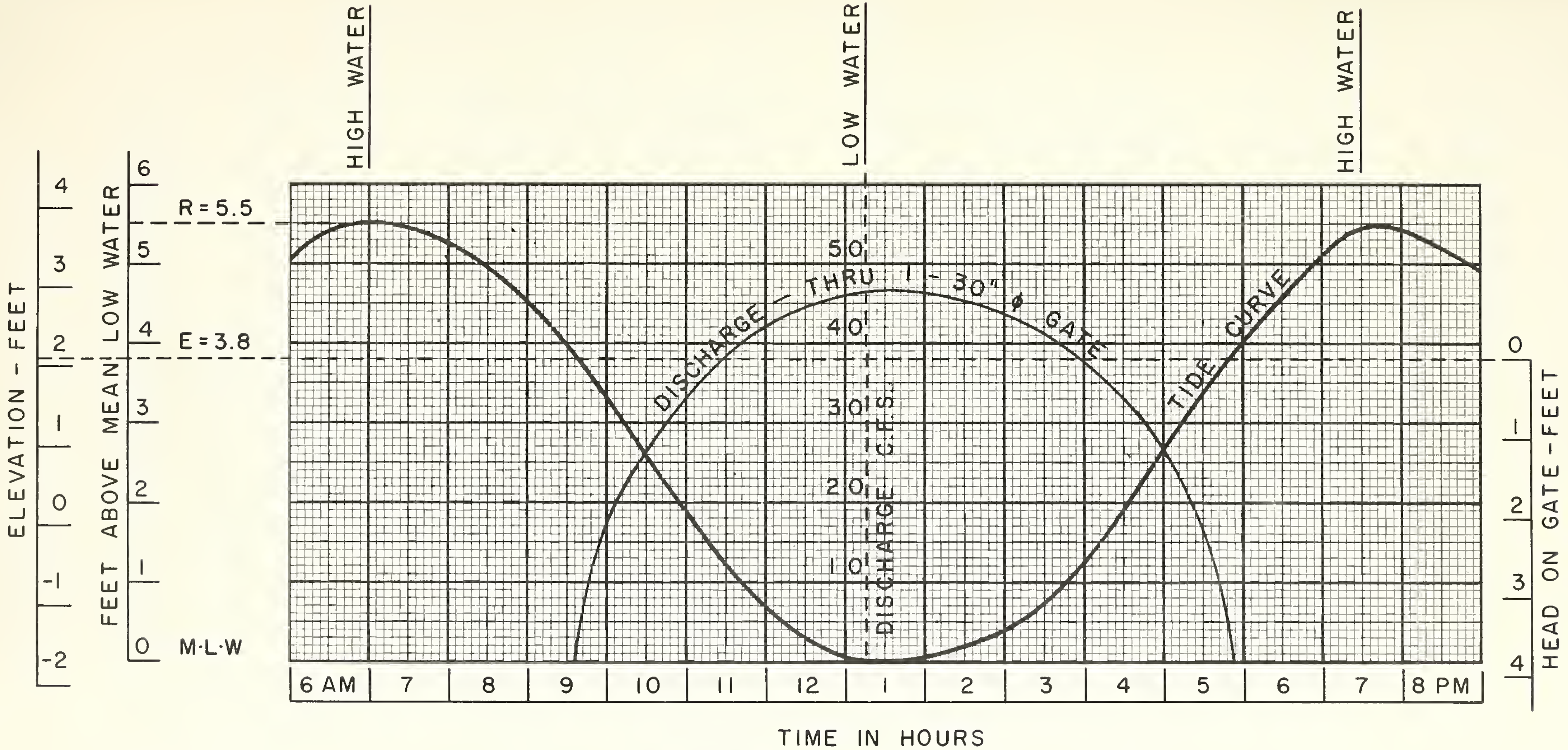
| Observed Tide Stages | | | | | | | |
|---|---|---|---|---|---|---|---|
| Time | | | Gage Height | Height Above Mean Low Water 1/ | E 2/ | Head on Gate 3/ | Gate Discharge 4/ |
| | Hour | Minute | Feet | Feet | Feet | Feet | cfs |
| AM | 6 | 02 | 3.0 | 4.7 | 3.8 | | |
| | 7 | 00 | 3.8 | 5.5 = R | | | |
| | 8 | 00 | 3.5 | 5.2 | | | |
| | 9 | 00 | 2.8 | 4.5 | | | |
| | | | | | | 0 | 0 @ 9H36M |
| | 10 | 00 | 1.5 | 3.2 | | 0.6 | 18.3 |
| | 11 | 01 | 0.2 | 1.9 | | 1.9 | 32.5 |
| M | 12 | 00 | -1.0 | 0.7 | | 3.1 | 41.6 |
| | 1 | 02 | -1.7 | 0.0 | | 4.0 | 47.2 |
| | 2 | 00 | -1.6 | 0.1 | | 3.9 | 46.6 |
| | 3 | 00 | -1.3 | 0.4 | | 3.4 | 43.6 |
| | 4 | 00 | -0.5 | 1.2 | | 2.6 | 37.9 |
| | 5 | 00 | 0.9 | 2.6 | | 1.2 | 25.9 |
| | | | | | | 0 | 0 @ 5H36M |
| | 5 | 58 | 2.2 | 3.9 | | | |
| | 7 | 00 | 3.5 | 5.2 | | | |
| | 8 | 00 | 3.7 | 5.4 | | | |
| PM | 9 | 00 | 3.2 | 4.9 | | | |

1/ Mean low water = elevation -1.7 R = tidal range

2/ Distance of design water elevation in gate forebay above mean low water (0.0 on tidal range)

3/ Head on gate = E less height above mean low water

4/ Discharge for selected 30" Ø gate from table 2 or figure 5




$$\text{Average Rate Of Discharge} = \frac{\text{Total Discharge Thru Cycle}}{\text{Time Of Cycle}}$$

$$= \frac{7.33^{\square''} \times 20 \text{ c.f.s. (Vertical Scale)} \times 2 \text{ Hrs. (Horizontal Scale)}}{12.4 \text{ Hrs.}}$$

$$= 23.6 \text{ c.f.s.}$$

# EXAMPLE: Determination of Gate Capacity for Variable Shaped Tide Curves

Figure 3

expensive construction, if possible. Surveys should tie all tidal observations and measurements into bench marks on the site survey.

## Required Drainage Discharge

The design of the outlet system should be based on the same drainage coefficients applicable to the adjoining nontidal lands. Such coefficients are prescribed by local technical and drainage guides. In the Northeast, these provide generally for drainage requirements equal to or better than "D" curve for hay and pasture land, "C" curve for general rotated crops, and "B" curve for truck crops.

Effects of prolonged wind tide, adjoining river flood flows, or other factors may require consideration of a high degree of protection from surface flooding within the protected area. Required discharge can be determined on a basis similar to that required for pumping. If pumping requirements are not established locally, good estimates can be established by first determining the interval of protection that can be justified economically and the corresponding 24-hour storm intensity for such period. The amount of rainfall to be removed in a 24-hour period will be the inches of rainfall for the storm less the inches that can be temporarily stored in forebay impoundments, channels, and the soil profile. Usually, the design for storm intensities of 2-year frequency is ample for hay and pasture lands, 5-year for rotated crops, and 10- to 20-year for truck crops.

## Design Hydraulic Gradient

In determining the hydraulic requirements of the outlet channel culverts and gates, the hydraulic gradient for the highest allowable water surface should be established for a basis of design. This establishes the highest level for storage of water in the forebay and also establishes the design heads through the culverts and gates. Usually, such gradients are set about a foot below the surface of the ground. See figure 4. Thus, some additional in-bank storage and gate capacity is available when storms or wind cause higher tides and corresponding reduction in the time of gate play. Besides setting the gradient as high at the forebay as feasible, it should be established to provide as long and uniform a grade upstream as possible so that no constricting channel cross sections are developed during fluctuating water stages.

## Determining Culvert and Gate Elevation and Size

Gate and culvert capacity may be determined on the basis of the general orifice formula $Q = CA \sqrt{2gh}$ where a conservative value of "C" for a properly hung gate on culvert lengths not in excess of 50 feet can be taken as 0.6. Correction for additional head losses must be made for culvert lengths in excess of 50 feet.

From the optimum forebay stage established for the design hydraulic gradient, the head and corresponding discharges as noted in

Drainage Area 700 Acres. — No Fore Bay Storage.

Required Channel Capacity (Curve C Drainage) 46 cfs.

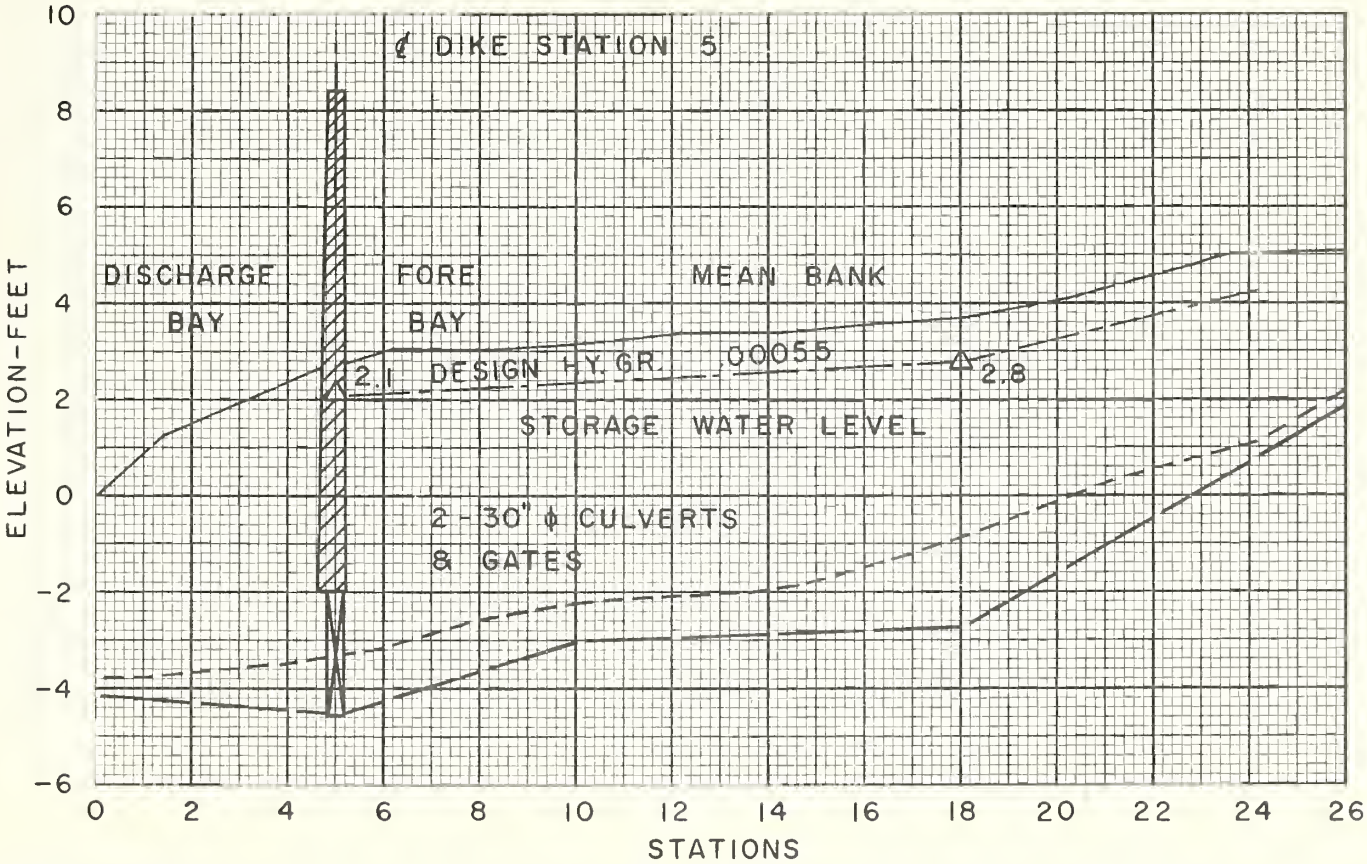
Peak Capacity 30" $\phi$ Gate = 46 cfs. — 2 Gates = 92 cfs.

Channel Capacity (Depth $5\frac{1}{2}$'-Bottom 5' – Side Slope 1:1) 114 cfs.

Channel Storage = $500 \times \frac{75+50}{2} + 800 \times \frac{50+44}{2} + 800 \times \frac{44}{2} = 86450$ Cu. Ft.

Equivalent Reduction In Flow For Storage $\frac{86450}{44640} = 1.9$ cfs.

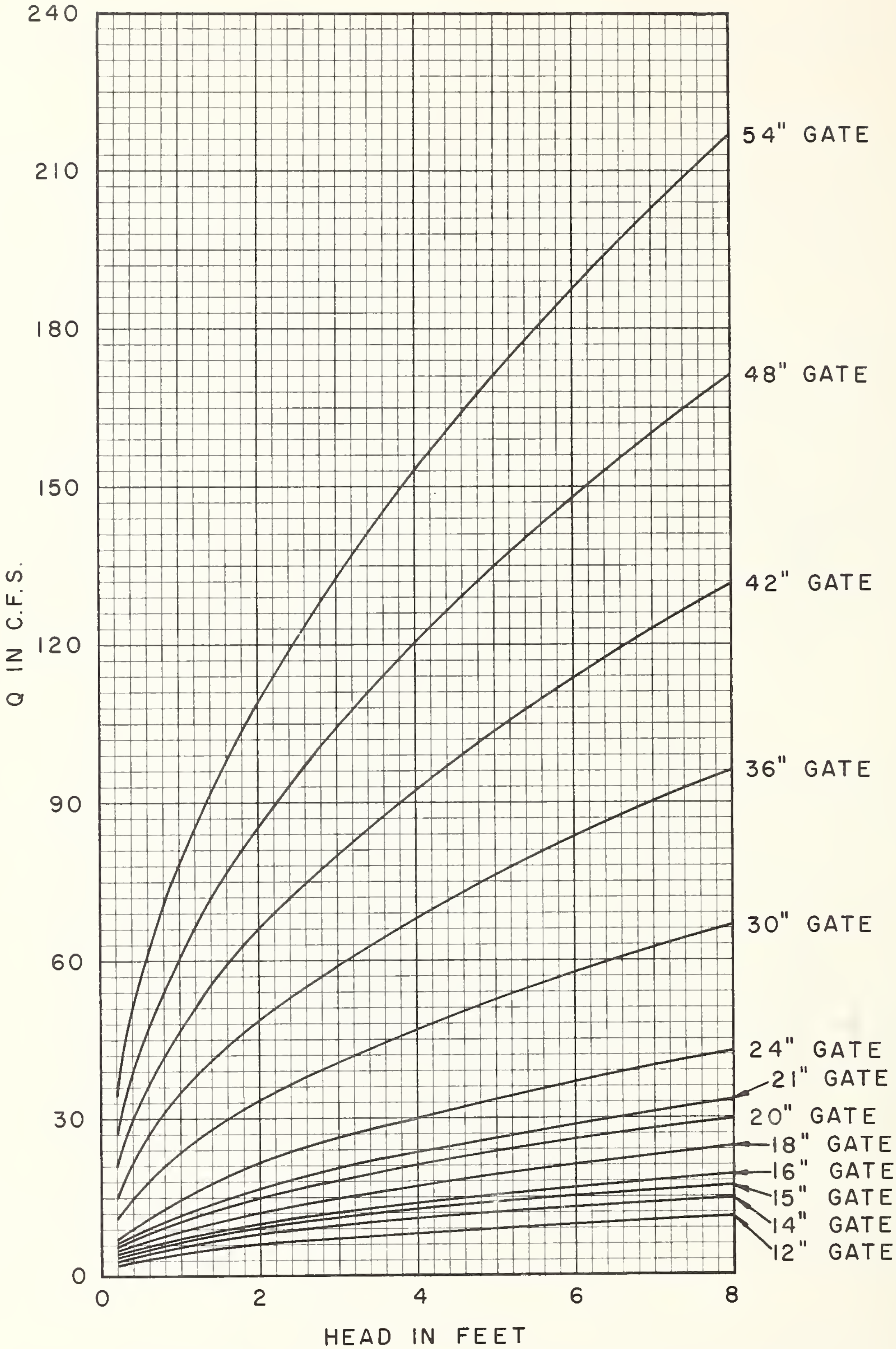
Required Channel Capacity At Peak Gate Flow = 92 – 2 = 90 cfs.




EXAMPLE: Determination of Channel Section for Forebay

Figure 4

Based on $Q = CA\sqrt{2gh}$ Where $C = 0.6$




CAPACITY OF CIRCULAR GATES
SUBMERGED OUTLET FLOWING FULL

Figure 5

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table 1 and figure 3 can be determined. Referring to figure 3, the design forebay water is established as elevation 3.8. Then available head at say 11:00 a.m. is equal to the vertical distance between the tide curve and elevation 3.8, or 1.9 feet. Discharge for a selected gate size can then be computed or taken directly from table 2 or the chart in figure 5. By determination of a sufficient number of discharges over the tidal cycle, a time-discharge curve, such as is shown superimposed on the tidal curve in figure 3, can be established. The area under this curve is the total discharge for the tidal cycle. This discharge, divided by the total time of the cycle, gives the average rate of discharge.

The size and number of gates selected depends upon such factors as permissible depths of excavations, clearances, size of structure, and availability and cost of various sized pipes and gates.

When the shape of the tidal curve conforms to the theoretical curves in figure 2, required pipe and gate sizes can be selected directly from the curves in figure 6. Here again, E represents the distance of the forebay stage above mean low water and R the tidal range. Referring to the example in figure 3 to illustrate use of the chart (and recognizing that the curve may not conform exactly to the standard curves in figure 1), E equals 3.8 and R equals 5.5. Projecting horizontally to the right on the chart in figure 6 to the approximate location of R equals 5.5; thence vertically downward to the 30-inch pipe; and thence horizontally left to the scale, a mean discharge of about 23 cfs is indicated. If the required Q for a 700-acre watershed, based on C curve drainage, is 46 cfs, then two 30-inch gates would be used for the mean gate capacity of the tidal cycle shown on figure 3.

## Forebay Channel Section

The forebay channel must not only have capacity to deliver the design drainage discharge to the forebay at the established hydraulic gradient, but it must also have such additional capacity as is necessary to pass the peak design discharges which the gates must deliver at low tide and provide some storage during low flows or short period of gate closure at high tide. This extra capacity can be reduced by the amount of storage in the forebay area. The peak capacity of the gate may be several times that of the mean discharge. Referring to table 2, the 30-inch gate will handle 46.1 cfs, or 2 gates will handle 92.2 cfs. Such required peaks can be determined directly for theoretical tide curves by use of the chart in figure 7. Referring to the example profile in figure 4, a channel 5½ feet deep, with a 5-foot bottom and 1 to 1 side slopes will provide for 114 cfs, which is more than sufficient to handle the required peak less the small equivalent discharge allowed for storage.

In selecting the channel cross section, it should be seen that ample depth and capacity are available at lower stages of flow resulting from fluctuations in forebay head.

Table 2

Capacity of Circular Gates *

| Gate Size - Inches | 12 | 14 | 15 | 16 | 18 | 20 | 21 | 24 | 30 | 36 | 42 | 48 | 54 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gate Area - Sq. Ft. | .79 | 1.07 | 1.23 | 1.40 | 1.77 | 2.18 | 2.41 | 3.14 | 4.91 | 7.07 | 9.62 | 12.57 | 15.90 |
| Hydr. Head - Feet | | | | | | | | | | | | | |
| .2 | 1.70 | 2.30 | 2.64 | 3.01 | 3.81 | 4.69 | 5.18 | 6.75 | 10.56 | 15.20 | 20.68 | 27.03 | 34.19 |
| .4 | 2.40 | 3.25 | 3.74 | 4.26 | 5.38 | 6.63 | 7.33 | 9.55 | 14.95 | 21.54 | 29.32 | 38.31 | 48.47 |
| .6 | 2.94 | 3.98 | 4.58 | 5.21 | 6.58 | 8.11 | 8.97 | 11.68 | 18.27 | 26.30 | 35.79 | 46.76 | 59.15 |
| .8 | 3.40 | 4.60 | 5.29 | 6.02 | 7.61 | 9.37 | 10.36 | 13.50 | 21.11 | 30.40 | 41.37 | 54.05 | 68.37 |
| 1.0 | 3.80 | 5.15 | 5.92 | 6.73 | 8.51 | 10.49 | 11.59 | 15.10 | 23.62 | 34.01 | 46.27 | 60.46 | 76.48 |
| 1.2 | 4.16 | 5.64 | 6.48 | 7.38 | 9.34 | 11.49 | 12.70 | 16.55 | 25.88 | 37.26 | 50.70 | 66.24 | 83.79 |
| 1.4 | 4.49 | 6.08 | 6.99 | 7.95 | 10.05 | 12.38 | 13.69 | 17.84 | 27.89 | 40.16 | 54.64 | 71.40 | 90.31 |
| 1.6 | 4.65 | 6.30 | 7.24 | 8.25 | 10.43 | 12.84 | 14.19 | 18.49 | 28.92 | 41.64 | 56.66 | 74.04 | 93.65 |
| 1.8 | 5.10 | 6.91 | 7.95 | 9.04 | 11.43 | 14.08 | 15.57 | 20.28 | 31.72 | 45.67 | 62.15 | 81.20 | 102.71 |
| 2.0 | 5.37 | 7.28 | 8.36 | 9.52 | 12.04 | 14.82 | 16.39 | 21.35 | 33.39 | 48.08 | 65.41 | 85.48 | 108.12 |
| 2.2 | 5.64 | 7.64 | 8.78 | 10.00 | 12.64 | 15.57 | 17.21 | 22.42 | 35.06 | 50.48 | 68.69 | 89.75 | 113.53 |
| 2.4 | 5.89 | 7.98 | 9.18 | 10.44 | 13.20 | 16.26 | 17.98 | 23.42 | 36.63 | 52.74 | 71.77 | 93.77 | 118.61 |
| 2.6 | 6.13 | 8.30 | 9.53 | 10.84 | 13.69 | 16.85 | 18.62 | 24.24 | 37.87 | 54.50 | 74.13 | 96.85 | 122.49 |
| 2.8 | 6.36 | 8.61 | 9.90 | 11.27 | 14.25 | 17.55 | 19.40 | 25.28 | 39.53 | 56.91 | 77.44 | 101.19 | 128.00 |
| 3.0 | 6.58 | 8.91 | 10.25 | 11.66 | 14.74 | 18.16 | 20.08 | 26.16 | 40.90 | 58.89 | 80.13 | 104.71 | 132.45 |
| 3.2 | 6.80 | 9.21 | 10.59 | 12.05 | 15.24 | 18.77 | 20.75 | 27.04 | 42.28 | 60.87 | 82.83 | 108.23 | 136.90 |
| 3.4 | 7.01 | 9.49 | 10.91 | 12.42 | 15.70 | 19.34 | 21.38 | 27.85 | 43.55 | 62.71 | 85.33 | 111.50 | 141.03 |
| 3.6 | 7.21 | 9.77 | 11.23 | 12.78 | 16.16 | 19.90 | 22.00 | 28.67 | 44.83 | 64.55 | 87.83 | 114.76 | 145.17 |
| 3.8 | 7.41 | 10.04 | 11.54 | 13.13 | 16.60 | 20.45 | 22.61 | 29.45 | 46.06 | 66.32 | 90.24 | 117.92 | 149.14 |
| 4.0 | 7.60 | 10.29 | 11.83 | 13.47 | 17.03 | 20.97 | 23.18 | 30.21 | 47.23 | 68.01 | 92.54 | 120.93 | 152.96 |
| 4.2 | 7.79 | 10.55 | 12.13 | 13.80 | 17.45 | 21.49 | 23.76 | 30.96 | 48.41 | 69.71 | 94.85 | 123.95 | 156.77 |
| 4.4 | 7.97 | 10.88 | 12.41 | 14.13 | 17.86 | 22.00 | 24.32 | 31.68 | 49.54 | 71.34 | 97.07 | 126.83 | 160.43 |
| 4.6 | 8.15 | 11.04 | 12.69 | 14.45 | 18.27 | 22.50 | 24.87 | 32.40 | 50.67 | 72.96 | 99.28 | 129.72 | 164.09 |
| 4.8 | 8.33 | 11.28 | 12.96 | 14.76 | 18.66 | 22.98 | 25.40 | 33.10 | 51.75 | 74.52 | 101.39 | 132.49 | 167.59 |
| 5.0 | 8.50 | 11.51 | 13.23 | 15.06 | 19.05 | 23.46 | 25.93 | 33.79 | 52.83 | 76.07 | 103.51 | 135.25 | 171.08 |
| 5.2 | 8.67 | 11.74 | 13.49 | 15.36 | 19.42 | 23.91 | 26.44 | 34.45 | 53.86 | 77.56 | 105.53 | 137.89 | 174.42 |
| 5.4 | 8.83 | 11.96 | 13.75 | 15.65 | 19.79 | 24.37 | 26.94 | 35.11 | 54.89 | 79.04 | 107.55 | 140.53 | 177.76 |
| 5.6 | 9.00 | 12.19 | 14.01 | 15.95 | 20.16 | 24.83 | 27.45 | 35.76 | 55.92 | 80.53 | 109.57 | 143.17 | 181.10 |
| 5.8 | 9.16 | 12.40 | 14.26 | 16.23 | 20.51 | 25.27 | 27.93 | 36.39 | 56.91 | 81.94 | 111.50 | 145.69 | 184.28 |
| 6.0 | 9.31 | 12.60 | 14.49 | 16.49 | 20.85 | 25.68 | 28.39 | 36.99 | 57.84 | 83.28 | 113.32 | 148.07 | 187.30 |
| 6.2 | 9.46 | 12.82 | 14.74 | 16.77 | 21.20 | 26.12 | 28.87 | 37.62 | 58.82 | 84.70 | 115.25 | 150.59 | 190.48 |
| 6.4 | 9.61 | 13.02 | 14.97 | 17.04 | 21.54 | 26.53 | 29.33 | 38.21 | 59.75 | 86.04 | 117.08 | 152.98 | 193.50 |
| 6.6 | 9.76 | 13.23 | 15.20 | 17.30 | 21.88 | 26.94 | 29.79 | 38.81 | 60.69 | 87.39 | 118.90 | 155.37 | 196.52 |
| 6.8 | 9.91 | 13.43 | 15.44 | 17.57 | 22.21 | 27.36 | 30.25 | 39.41 | 61.62 | 88.73 | 120.73 | 157.75 | 199.55 |
| 7.0 | 10.06 | 13.62 | 15.66 | 17.82 | 22.53 | 27.75 | 30.68 | 39.97 | 62.50 | 90.00 | 122.46 | 160.02 | 202.41 |
| 7.2 | 10.20 | 13.81 | 15.88 | 18.07 | 22.85 | 28.14 | 31.11 | 40.54 | 63.39 | 91.27 | 124.19 | 162.28 | 205.27 |
| 7.4 | 10.34 | 14.01 | 16.10 | 18.33 | 23.17 | 28.54 | 31.55 | 41.10 | 64.27 | 92.55 | 125.93 | 164.54 | 208.13 |
| 7.6 | 10.48 | 14.20 | 16.32 | 18.58 | 23.49 | 28.93 | 31.98 | 41.67 | 65.16 | 93.82 | 127.66 | 166.80 | 210.99 |
| 7.8 | 10.62 | 14.38 | 16.53 | 18.82 | 23.79 | 29.30 | 32.39 | 42.20 | 65.99 | 95.02 | 129.29 | 168.94 | 213.70 |
| 8.0 | 10.75 | 14.56 | 16.74 | 19.05 | 24.09 | 29.67 | 32.80 | 42.74 | 66.83 | 96.22 | 130.93 | 171.08 | 216.40 |

* Based on $Q = .6\ A\ \sqrt{2gh}$ - Pipe Flowing Full with Outlet Submerged

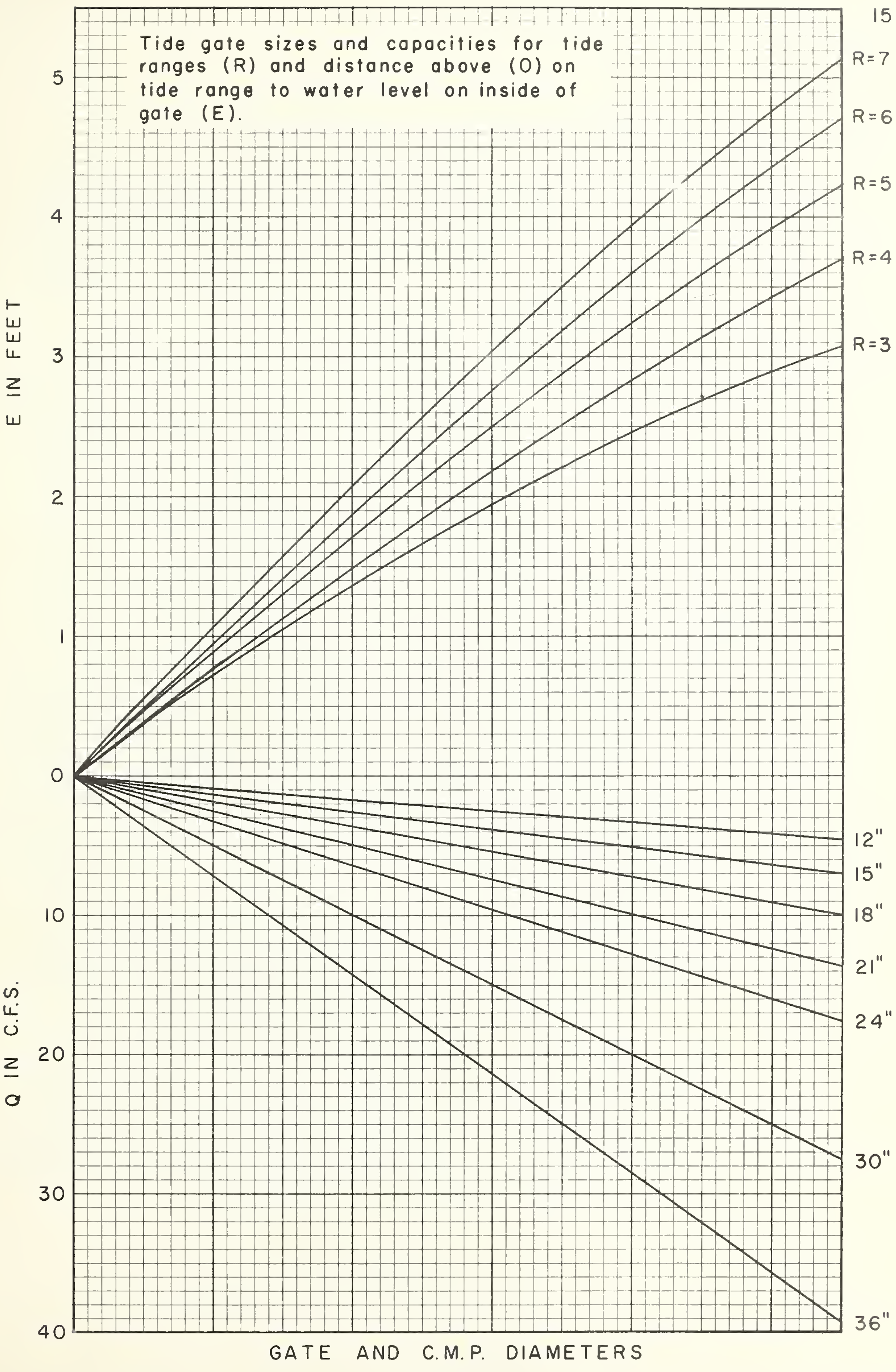



Figure 6

1-31-63

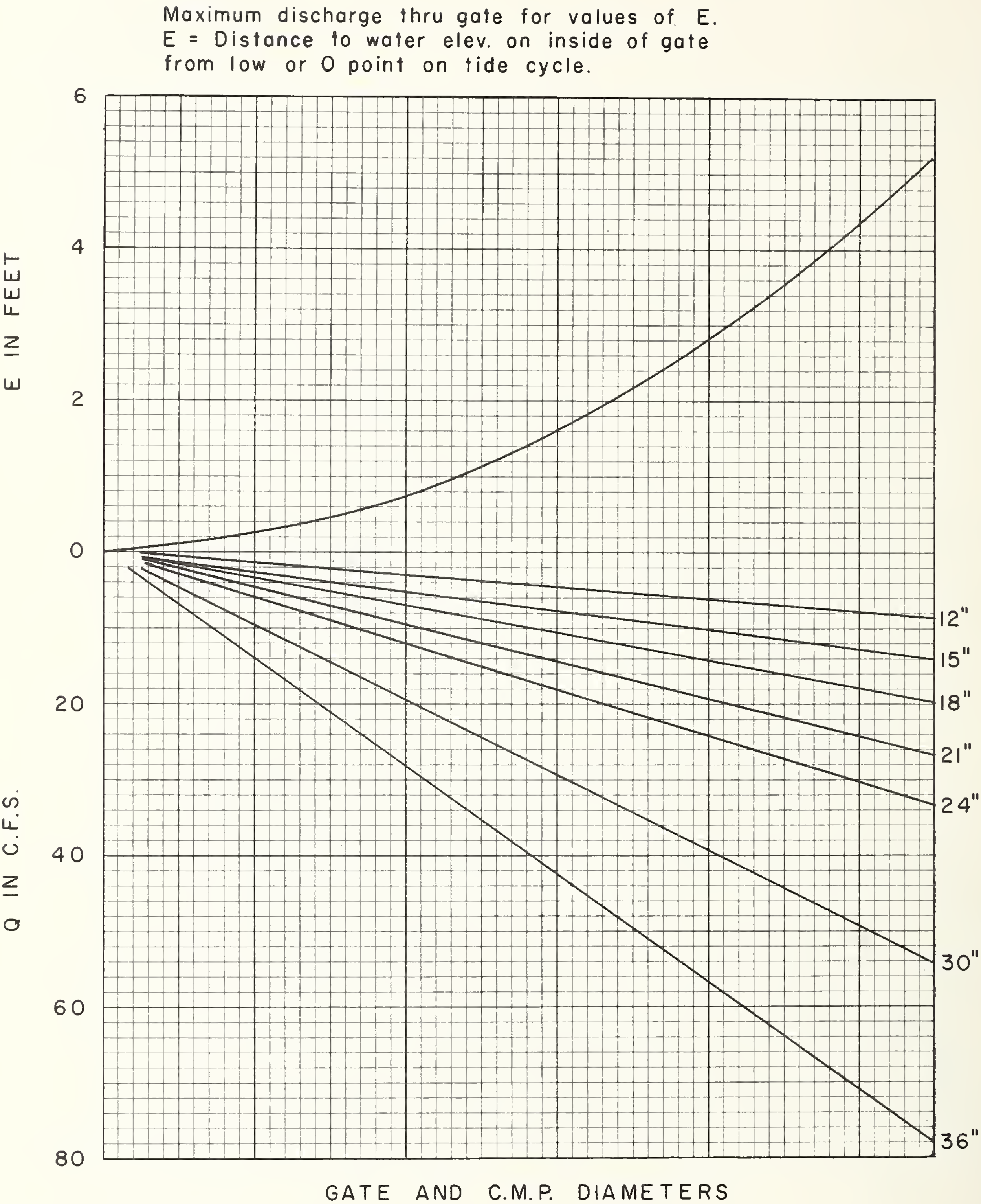

Maximum discharge thru gate for values of E.
E = Distance to water elev. on inside of gate from low or O point on tide cycle.
6
4
2
0
20
40
60
80
E IN FEET
Q IN C.F.S.
12"
15"
18"
21"
24"
30"
36"
GATE AND C.M.P. DIAMETERS

Figure 7

## Discharge Bay Channel Section

The discharge bay section of the channel should be designed or natural channels checked to see that ample depth and capacity are available for discharging designed flow to deep open water without causing backwater at the gates. Usually, low foreshore banks provide ample overflow area to accommodate such discharge if depth and approximate bottom widths are not too much smaller than the designed upstream section.

## Installation of Culverts and Gates

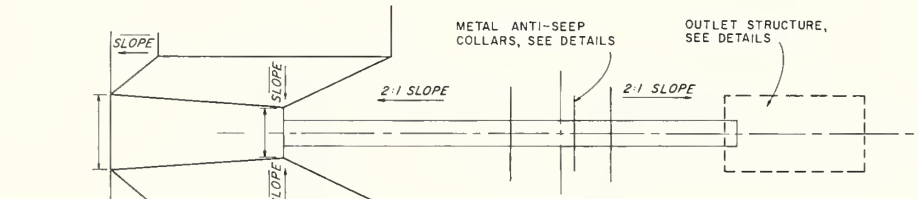
Usually, tidal structures are located in wet, swampy sites where construction is difficult. Sites sometimes can be relocated to slightly higher and more stable locations to one side of the natural channel handling the flow. After installation of the structure and gate, lead channels can be dug to and from the structure into the natural channel or to a newly constructed ditch. Structural sites and channels usually are excavated by draglines, which also serve as cranes for hoisting pipes, gates, and other structural sections into place. During construction, the site is ordinarily isolated from surface water by encircling the area with spoil dikes and the pit dewatered by high capacity diaphragm pumps. Sheet piling is sometimes necessary to shore up the sidewalls of the excavation.

An outlet structure usually is necessary to protect the gate and embankment from scour and floating debris. Treated timber structures, as illustrated in the standard design, figure 8, have proven practical and most economical to install. This standard, which the Soil Conservation Service in New Jersey has modified by experience, has been developed from similar structures long used in cranberry bogs and marshland along the east coast. The structures can be prefabricated in whole or part, depending upon size, and set into place by the dragline for attachment to preset piles that have been driven or jetted into the foundation.

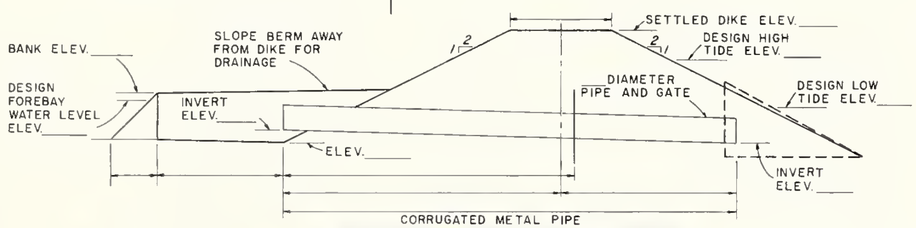
Of the types of corrugated metal pipe available for use, the pure iron asbestos bonded pipe should be used. Experience has shown that non-coated and standard alloy steel pipe have a relatively short life in brackish and often acid foundation waters of such sites.

The culvert conduit and gate, unless of very small size, should be installed as separate units. Usually, a short or stub section of conduit is fabricated to the gate and joined to the culvert after both are placed into the trench. Camber should be provided in the excavated trench bed to allow for consolidation and unequal loading by the superimposed dike. Conduit and gate must be set true to line and grade if the structure is to operate as designed.

# DRAINAGE FLAP GATE INSTALLATION WITH TIMBER OUTLET STRUCTURE

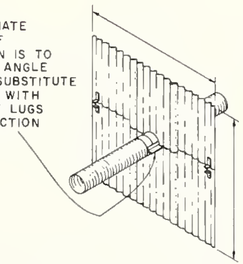


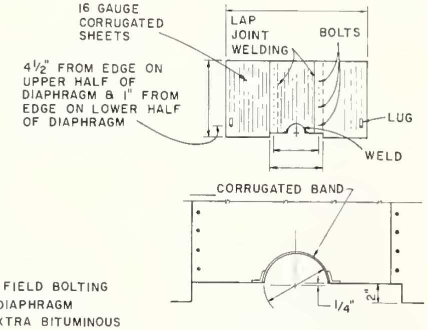

PLAN VIEW




PROFILE ALONG CENTERLINE OF PIPE

AN ALTERNATE METHOD OF CONNECTION IS TO ELIMINATE ANGLE IRONS, & SUBSTITUTE 4½" RODS, WITH TANK TYPE LUGS FOR CONNECTION






ANTI-SEEP COLLARS

NOT TO SCALE

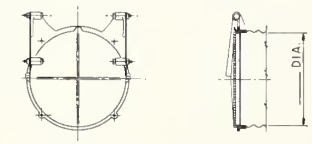
NOTES

HOLES MATCH PUNCHED IN SHOP TO PERMIT FIELD BOLTING

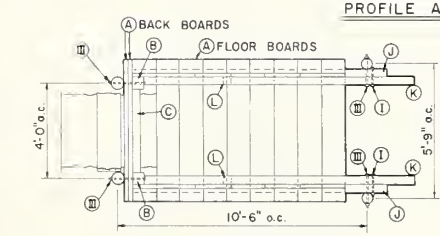
GALVANIZED BOLTS TO BE FURNISHED WITH DIAPHRAGM

LAP BETWEEN TWO SECTIONS TO RECEIVE EXTRA BITUMINOUS COATING AT TIME OF ASSEMBLY

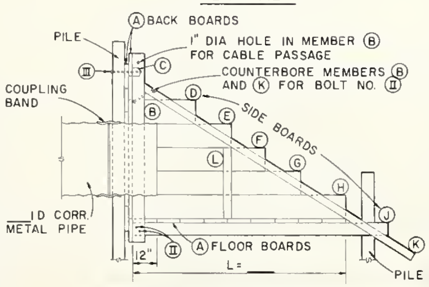
DIAPHRAGM TO BE FULLY BITUMINOUS COATED




TYPICAL FLAP GATE

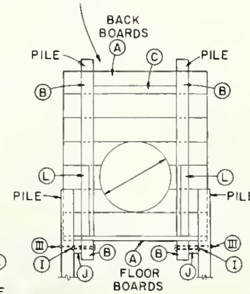



PLAN VIEW




PROFILE ALONG CENTERLINE

NOTE: MEMBER Ⓚ AND SIDE BOARDS NOT SHOWN




FRONT VIEW

TIMBER OUTLET STRUCTURE DETAILS

## GENERAL NOTES

1. BACK BOARDS TO BE NAILED TO MEMBER Ⓑ AND NAILED TOGETHER WITH NAILS AT 6" O C
2. SIDE BOARDS TO BE NAILED TO MEMBERS Ⓑ AND Ⓚ.
3. FLOOR BOARDS SHALL BE NAILED TO MEMBER Ⓙ.
4. NAILS SHALL BE PAINTED OR COATED.
5. ALL NAILS AND BOLTS WILL BE GALVANIZED
6. MINIMUM LENGTH OF PILES SHALL BE 2 TIMES THE LENGTH OF MEMBER Ⓑ.
7. TIP END OF PILES SHALL BE A MINIMUM OF 6" DIA.
8. PILES SHALL BE DRIVEN OR JETTED IN PLACE.
9. PILES AND TIMBER SHALL BE CREOSOTE TREATED
10. L = LENGTH OF FLOOR.
11. ASBESTOS BONDED BITUMINOUS COATED CORRUGATED METAL PIPE SHALL BE USED
12. WATER TIGHT COUPLING BANDS SHALL BE USED AT ALL PIPE JOINTS.
13. TIMBER QUANTITIES BASED ON DRESSED SIZES
14. FLAP GATE SHALL BE ARMCO MODEL 10-C OR APPROVED EQUAL, WITH BRONZE BUSHINGS, BOLTS AND HINGE BARS

| BOLT QUANTITIES | | | |
|---|---|---|---|
| MARK | SIZE | QUANTITY | UNIT |
| I | 3/4" 10" | 2 | EACH |
| II | 3/4" 12" | 6 | EACH |
| III | 3/4" 24" | 4 | EACH |

EACH BOLT SUPPLIED WITH A AND 2 WASHERS.

| NAIL QUANTITIES | | |
|---|---|---|
| SIZE | QUANTITIES | UNIT |
| 20d | 12.5 | POUNDS |
| 40d | 3.0 | POUNDS |
| 60d | 3.0 | POUNDS |

| PIPE DIAMETER | L = FLOOR LENGTH |
|---|---|
| 12" - 15" | 7' – 0" |
| 18" - 21" | 8' – 0" |
| 30" - 36" | 9' – 0" |

| MEMBER | PIPE DIAMETER | |
|---|---|---|
| | 12" - 13" - 18" | 21" - 30" - 36" |
| A | 2" x 12" x 5'-0" | 2" x 12" x 6'-0" |
| B | 6" x 6" x 6'-0" | 6" x 6" x 8'-0" |
| C | 4" x 4" x 2'-8" | 4" x 4" x 3'-8" |
| D | 2" x 12" x 2'-4" | 2" x 12" x 2'-8" |
| E | 2" x 12" x 3'-8" | 2" x 12" x 4'-2" |
| F | 2" x 12" x 4'-11" | 2" x 12" x 5'-7" |
| G | 2" x 12" x 6'-2" | 2" x 12" x 7'-1" |
| H | 2" x 12" x 8'-0" | 2" x 12" x 9'-0" |
| J | 4" x 6" x 9'-5" | 4" x 6" x 10'-9" |
| K | 4" x 4" x 11'-3" | 4" x 4" x 13'-7" |
| L | 4" x 4" x 3'-0" | 4" x 4" x 3'-0" |

| TIMBER QUANTITIES | | | |
|---|---|---|---|
| ITEM | QUANTITY | | UNIT |
| | 12"-15"-18" DIA | 21"-30"-36" DIA | |
| 2" x 12" | 330.35 | 390.02 | BOARD FT |
| 4" x 4" | 41.55 | 49.10 | BOARD FT |
| 4" x 6" | 37.68 | 43.00 | BOARD FT |
| 6" x 6" | 48.00 | 48.00 | BOARD FT |
| TOTAL | 457.58 | 530.12 | BOARD FT |

Technical Approval: Harold M. Kautz

Head E & WP UNIT DATE

| Prepared By ENGINEERING & WATERSHED PLANNING UNIT DESIGN SECTION UPPER DARBY, PENNSYLVANIA | APPROVED: ____________ HEAD, ENGINEERING AND WATERSHED PLANNING UNIT DATE ____________ | U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ASSISTING ____________ SOIL CONSERVATION DISTRICT | DRAWING NO. ESNE - 60 SHEET ______ OF ______ DATE JANUARY '63 |
|---|---|---|---|

Figure 8

# APPENDIX A

## The Equilibrium Tide

The attraction of sun and moon upon the great masses of surface waters on the revolving earth cause periodic rising and falling of ocean levels that are observed along shore lines of coastal waters. The range of such rises and falls varies from place to place. The following is a brief accounting of such phenomenon.

The mass of the sun is 27 million times greater than the mass of the moon. However, the mean distance between earth and moon is 389 times less than the mean distance between earth and sun. Based on elementary principles of physics that gravitational attraction between two bodies varies inversely as the square of the distance between them and on the hypothesis that attraction between spheres is the same as if their respective masses are applied at their centers, computed forces exerted by the sun upon the earth are less than half (46 percent) that of the moon. The attraction between the moon and any individual unit mass on the earth also depends on the distance of the unit from the center of the moon, which is not quite the same as the distance from the center of the earth to the center of the moon. Thus, tides are produced by the varying differences between the attraction of the moon upon a unit mass at the surface of the earth and its attraction per unit of mass on the earth as a whole, together with corresponding differences in the attraction of sun upon these unit masses.

The maximum lunar pull on the earth's surface is at a point on the surface in direct line with the center of the earth and moon. At such point the surface waters are pulled away from the earth's surface on the side of earth towards the moon and the earth's surface is pulled away from the surface waters on the earth's side away from the moon. At the same time, lesser pulls are in effect at other points in proportion to the obliqueness of the line of pulls between the surface points and the earth's center. If the earth's surface were entirely covered by water, a hypothetical lunar tide would amount to about 7 inches and solar tide about 3 inches. These small components of tide exert continuing periodic impulses over changing points of the oceans and seas as the earth spins daily in its orbit around the sun and the moon in its orbit around the earth. These forces in turn set into motion much greater and varied tidal surges. The flows generated by such welling masses of ocean water are augmented or diminished by the force of other currents, such as those circulations of ocean waters between equator and poles by the result of the earth's rotation and thermal differences over its surfaces, by the drag and deflections caused by the configurations of the ocean floor and shore lines, by the varied spacing of land masses, and by amplification and damping of oscillating waters set up by return currents between such land masses.

The earth revolves on its axis once each solar day but requires an additional 50 minutes of time to complete one lunar day. Two solar and two lunar tides occur daily, once when sun and moon are overhead and once when underfoot. Since the sun's tide producing force is less than half of the moon's, the solar force is noted principally for its effect in increasing or decreasing lunar tides. Each succeeding tide thus occurs later in time each solar day. Day by day, changes in range of the equilibrium tides also result from changing declination of the lunar and solar orbit. These run through cycles, whose respective periods are the periods of their declinations. The moon in its transit about its orbit crosses the celestial equator of the earth. After a week's descent to its maximum north position, it declines to recross the equator in about another week. It then descends to its maximum south position in about another week to return to its position at the equator. The full cycle requires a lunar month of 27-1/3 days.

As the sun appears to move along its path on the celestial sphere, it crosses the celestial equator of the earth with zero declination at the vernal equinox in late March to ascend north of the equator until a maximum of 23-1/2 degrees at the summer solstice in late June. Then declining, it crosses the equator at the autumnal equinox in late September to descend to its southerly position of about 23-1/2 degrees in late December. A period of 365 days completes the circuit.

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